# SYSTEMS AND METHODS THAT PROVIDE FREQUENCY DOMAIN SUPPLEMENTAL TRAINING OF THE TIME DOMAIN EQUALIZER FOR DMT

## Related Application Data

**[0001]** This application claims benefit of and priority to U.S. Application Serial No. 60/241,664 filed October 19, 2000, entitled "Frequency Domain Supplemental Training of the Time Domain Equalizer for DMT," which is incorporated herein by reference in its entirety.

## Background of the Invention

### Field of the Invention

**[0002]** In general, the systems and methods of this invention relate to time domain equalizer training. In particular, this invention relates to systems and methods for supplemental frequency domain training of the time domain equalizer in a discrete multi-tone system.

### Description of Related Art

**[0003]** In Discrete Multi-tone Modulation (DMT) systems, the time domain equalizer (TDQ) is a finite impulse response (FIR) filter located at the receiver side of a DSL modem. The TDQ is used to reduce the intersymbol interference (ISI). If the channel is shortened in time to have a length no greater than the length of the cyclic prefix, the intersymbol interference can be eliminated. Thus, a common method for training the TDQ in a DMT system is to jointly optimize the numerator and denominator of the autoregressive (AR) model for the channel where the order of the numerator is equal to the cyclic prefix length

and the denominator is used as the TDQ setting. The training is based on transmission and reception of a known reference signal, such as the reverb signal in ADSL systems, using a least squares fit of the AR channel model.

## SUMMARY OF THE INVENTION

**[0004]** The supplemental training according to the exemplary systems and methods of this invention starts with the least squares solution of the time domain equalizer coefficients outlined above as its starting point, and iteratively improves on it.

**[0005]** Specifically, the medley-based supplemental training which is the subject of this application takes as input the output of a reverb-based TDQ training algorithm. Examples of reverb-based training algorithms are described in Stuart Sandberg and Michael Tzannes, "Overlapped Discrete Multitone Modulation for High Speed Copper Wire Communications," IEEE JSAC, vol 13, no. 9, Dec 1995, pg 1571-1585, incorporated herein by reference in its entirety, and include channel shortening schemes based on an AR fit to the transmission channel.

**[0006]** The improvement is geared towards maximizing the number of bits per frame loaded over the TDQ choice. In particular, capacity is maximized directly rather than setting a goal to shorten the channel and hoping that the capacity would be maximized as a result. The supplemental training operates in medley transmission mode, and requires a number of pseudo-random data frames.

**[0007]** Medley operation is selected in that the reverb data transmission, which is the repetitive transmission of the same reference frame, would not produce ISI in the received signal, and the SINR (Signal-to-Interference and Noise) determined in this way would not take into account the very component of error that the TDQ is intended to reduce. From the medley data, the SINR can be estimated over the bins used in the actual data transmission mode, and therefore, the number of bits per frame loaded.

**[0008]** The systems and methods of this invention use a directed search method on the capacity function to obtain an improved TDQ. The function in question is highly non-linear, and after linearization, e.g., using the first two terms in a Taylor series expansion around the starting TDQ point, a local extremum is sought. Since this does not guarantee the best solution, the same supplemental training can be repeated one or more times, each time starting with the TDQ solution resulting from the previous run.

**[0009]** In accordance with an exemplary embodiment of the invention, an aspect of the invention relates to performing frequency domain supplemental training of a time domain equalizer.

**[0010]** Additionally, aspects of the invention also relate to performing frequency domain supplemental training of a time domain equalizer in a discrete multi-tone environment.

**[0011]** Additional aspects of the invention also relate to performing the supplemental training numerous times, with each instance of the supplemental training using the last determined time domain equalizer coefficients to improve the quality of the results.

**[0012]** These and other features and advantages of this invention are described in, or are apparent from, the following detailed description of the embodiments.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0013]** The embodiments of the invention will be described in detail, with reference to the following figures wherein:

**[0014]** Fig. 1 is a functional block diagram illustrating a DMT DSL modem according to this invention;

**[0015]** Fig. 2 illustrates how supplemental training fits into a sequence of ADSL receiver initialization/training tasks; and